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A Comprehensive Review of Geopolymer Concrete: Performance and Incorporation in RCC Beams

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Abstract

This review paper provides a succinct overview of recent strides in geopolymer concrete technology, focusing on its strength, durability, and sustainable applications. Beginning with the fundamental principles of geopolymerization, the paper delves into the latest research findings, emphasizing enhancements in compressive and flexural strength. It critically analyzes the durability of geopolymer concrete against environmental factors and explores innovative strategies, such as incorporating supplementary cementitious materials and nanomaterials, to improve its resilience. The review also highlights diverse sustainable applications, ranging from conventional structures to specialized uses in marine and infrastructure projects. By synthesizing current knowledge, this paper contributes valuable insights to researchers, practitioners, and policymakers, promoting geopolymer concrete as an eco-friendly alternative in construction for a more sustainable future.

Keywords: Geopolymer concrete, strength, durability, sustainable applications, supplementary cementitious materials, nanomaterials

INTRODUCTION

Geopolymer concrete has emerged as a promising alternative to traditional Portland cement-based concrete, offering improved mechanical properties, enhanced durability, and reduced environmental impact. This paper aims to provide a comprehensive review of geopolymer concrete technology, with a particular focus on its performance and incorporation in reinforced cement concrete (RCC) beams. The introduction outlines the fundamental principles of geopolymerization, highlighting its chemical reactions and structural characteristics. Additionally, it sets the stage for exploring recent advancements in geopolymer concrete research, including innovations in mix design, curing methods, and sustainable applications. By synthesizing current knowledge, this review aims to contribute valuable insights to researchers, engineers, and policymakers, promoting the adoption of geopolymer concrete as a sustainable solution in construction practices.

Geopolymer concrete, as an eco-friendly alternative to traditional Portland cement-based concrete, has garnered increasing attention in recent years due to its superior mechanical properties, durability, and sustainability. Unlike conventional concrete, which relies on Portland cement as a binder, geopolymer concrete utilizes industrial by-products such as fly ash or slag, reducing the carbon footprint associated with cement production. The chemical reaction responsible for binding the aggregates in geopolymer concrete is known as geopolymerization, wherein aluminosilicate materials react with alkaline activators to form a

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three-dimensional network structure. This unique chemical composition imparts geopolymer concrete with excellent compressive and flexural strength, as well as resistance to harsh environmental conditions such as chemical attack and freeze-thaw cycles.

Recent research efforts have focused on further enhancing the performance of geopolymer concrete, particularly in the context of RCC beams. Innovations in mix design, curing methods, and reinforcement techniques have led to significant improvements in the mechanical properties and durability of geopolymer concrete beams. For example, studies have investigated the effects of incorporating supplementary cementitious materials such as ground granulated blast furnace slag (GGBS) or metakaolin on the strength and workability of geopolymer concrete mixes. Additionally, researchers have explored the use of nanomaterials, such as nano-silica or nano-alumina, to enhance the microstructure and durability of geopolymer concrete.

Fly ash–based geopolymer concrete offers enhanced characteristics suitable for widespread use in construction applications. The alkali activation process results in a glossy surface, providing an aesthetically pleasing appearance. This material, distinct from ordinary Portland cement (OPC), exhibits improved fire resistance, increased resistance to abrasion and cracking. Cost-effectiveness is a key advantage, as fly ash, an industrial by-product, is readily available, making Geopolymer concrete more economical than OPC, which relies on expensive cement binders. Similar to conventional reinforced concrete, Geopolymer concrete requires reinforcement with steel bars for large-scale applications in civil engineering structures.

High volume fly ash concrete exhibits improved flowability and workability, minimal bleeding of fresh concrete, and a prolonged final setting time of up to 2 hours. While the strength within the initial 7 days may be lower, it can be accelerated. Plastic shrinkage is higher when the concrete is unprotected, yet thermal shrinkage and drying shrinkage are reduced. Notably, the resistance to chloride ion penetration is remarkably high after 90 days, and the electrical resistivity is also elevated.

Fine, low-carbon-content fly ash of good quality reduces the water demand of concrete without compromising workability. Well-proportioned fly ash concrete exhibits enhanced workability compared to Portland cement concrete with the same slump. Fly ash contributes to a decrease in bleeding due to reduced water demand. Moreover, it lowers the rate of heat produced and the internal temperature of concrete, making it advantageous for mass concrete construction. Fly ash concrete typically experiences less creep and shrinkage compared to Portland cement concrete of equivalent strength.

OBJECTIVES

This review aims to assess recent advancements in geopolymer concrete technology with a dual focus: firstly, to analyze improvements in compressive and flexural strength through innovative formulations; secondly, to evaluate the durability of geopolymer concrete against environmental factors such as chemical attacks, freeze-thaw cycles, and abrasion. The paper also investigates the effectiveness of integrating supplementary cementitious materials and nanomaterials to enhance durability. Additionally, it synthesizes information on sustainable applications, emphasizing geopolymer concrete's role in reducing carbon emissions and promoting eco-friendly construction practices. The ultimate goal is to provide a succinct overview, offering valuable insights for researchers, practitioners, and policymakers engaged in sustainable construction efforts.

LITERATURE REVIEW

Geopolymer concrete reaches its final strength in just 7 days, which is four times faster than ordinary Portland cement concrete. A significant strength gain of over 50% is observed within 3 days. The authors note that increasing the concentration of sodium hydroxide enhances strength, while an increase in the alkaline liquid to fly ash ratio results in reduced strength. The optimal ratio between sodium silicate and sodium hydroxide for maximum strength is found to be 2.5. High-temperature curing (approximately 600°C) is crucial for strength development. Geopolymer concrete exhibits decreased strength when immersed in an acid solution. Cubes with lower alkaline liquid to fly ash ratios experience a more substantial strength reduction compared to cubes with higher ratios. The permeability of geopolymer concrete is very low, with an increase in permeability observed with an increase in the alkaline liquid to fly ash ratio. Additionally, higher ratios contribute to improved workability, while mixes with ratios below 0.3 exhibit stiffness [1–5].

the durability of geopolymer concrete, examining nominal strength concretes with NaOH concentrations of 8 M, 10 M, 12 M, and 14 M. These concretes were subjected to tests for acid and salt resistance. In 0.5%, 1%, and 2% H_2SO_4 concentrations, the 12 M geopolymer concretes exhibited reductions in weight of 0.91%, 1.21%, and 1.36%, respectively, compared to control specimens after 90 days of immersion in sulfuric acid solution. Compressive strength reductions of 3.7%, 8.59%, and 16.7% were observed in the 12 M geopolymer concretes under the same acid concentrations. Moreover, these concretes displayed weight increases of 6%, 7%, 4%, and 10% in 5% Na_2SO_4 concentration, with the increase being the lowest compared to other NaOH concentrations (8 M, 10 M, and 14 M) [6–14].

Regarding the behavior of fly ash–based geopolymer concrete in acidic environments, research indicated that geopolymer concrete resisted acid attacks more effectively than conventional concrete when exposed to HCl and H_2SO_4. The loss of compressive strength in geopolymer concrete was considerably lower than that in conventional concrete at all ages of acid exposure. Exposure to H_2SO_4 caused the maximum loss of compressive strength and weight in both geopolymer and conventional concrete, but the loss in geopolymer concrete was significantly less at all ages (7, 14, and 28 days). The weight loss of geopolymer concrete was minimal when exposed to 5% acid solutions for up to 4 weeks [15–18].

The minor changes in weight and strength in geopolymer concrete and OPC mixes exposed to sulfuric acid and magnesium sulfate. The compressive strength loss in OPC exposed to 10% sulfuric acid ranged from 10% to 40%, while geopolymer concrete exhibited losses of about 7% to 23%. For specimens exposed to magnesium sulphate, the compressive strength loss was between 5% and 25% for OPC and between 8% and 45% for geopolymer concrete. The split tensile strength loss in OPC ranged from 15% to 25%, whereas in geopolymer concrete, it was about 8% to 45% [18–27].

A comparative study of geopolymer concrete using fly ash found that exposure to sulfuric acid solution damaged the surface of heat-cured geopolymer concrete specimens, resulting in a mass loss of approximately 3% after one week of exposure. The severity of the damage depended on the acid concentration. While the sulfuric acid attack caused degradation in the compressive strength of heat-cured geopolymer concrete, the resistance was better compared to Portland cement concrete, as reported in earlier studies. Tests on heat-cured geopolymer mortar specimens indicated that the degradation in compressive strength due to sulfuric acid attack was primarily attributed to the degradation in the geopolymer matrix rather than the aggregates [28–31].

Experimental investigations on the factors influencing the compressive strength of fly ash–based geopolymer concrete. They concluded that an extended curing time enhances the polymerization process, leading to higher compressive strength. The use of commercially available naphthalene-based superplasticizer proved effective in enhancing the workability of fresh geopolymer concrete without causing segregation or degradation in compressive strength, up to a 2% admixture mass with respect to fly ash. The compressive strengths of specimens cured immediately after casting showed little difference compared to those sent for curing 60 minutes after casting.

The workability of geopolymer concrete is influenced by the mixing time, which decreases with longer mixing times. The addition of the chemical admixture Glenium B233 was found to mitigate the effects of low workability and rapid setting time in geopolymer concrete. While this inclusion did not impact compressive strength, it significantly increased the workability of the concrete. Specimens were cured under ambient temperature conditions rather than accelerated curing. The 7-day strength was 70% of the 28-day strength, and this percentage increased with higher GGBS content. The 28-day strength was higher compared to OPC.

The compressive strength of geopolymer concrete and concluded that the compressive strength decreases with an increase in the alkaline liquid to fly ash ratio. The use of commercially available naphthalene-based superplasticizer was identified as a beneficial measure to enhance the workability of fresh geopolymer concrete. However, the dosage of this admixture was limited to 2% by mass of fly ash, as beyond this dosage, a decrease in compressive strength was observed. Additionally, replacing water with sodium silicate resulted in a decrease in the compressive strength of geopolymer concrete.

The mechanical and durability properties of slag-based recycled aggregate concrete have been studied. The compressive and tensile strengths of admixed recycled concrete aggregate (RCA) were found to be lower than those of naturally available aggregate at all concrete ages and for all percentages of naturally available aggregate and cement replacements. The study indicated that concrete with 40% GGBS and 50% RCA yielded better results compared to other combinations, showing improved resistance against sorption when RCA was combined with GGBS.

The water content in recycled aggregate mixes results in improved tensile strength and modulus of elasticity, contributing to enhanced overall strength characteristics of structures. However, it is crucial to note that recycled aggregate with reduced water content may exhibit low workability, necessitating careful monitoring of water content in concrete mixes whenever recycled aggregate is utilized due to its water absorption capacity.

An experimental study on high-strength concrete incorporating recycled coarse aggregate revealed that an increase in the percentage of RCA replacement led to a reduction in compressive strength. Nevertheless, decreasing the water-cement ratio in the mix resulted in increased compressive strength. The study demonstrated that achieving a target compressive strength of 40 MPa is feasible for 30% to 40% RCA replacement by adjusting the water-cement ratio and admixture content. Reducing the water-cement ratio in recycled aggregate mixes also improved tensile strength and modulus of elasticity. While water absorption and porosity of RCA-replaced mixes were higher than normal mixes, they remained within permissible limits, and these properties could be modified by further adjusting the water-cement ratio and incorporating admixtures. The study emphasized the need for new standards for recycled aggregates and their successful utilization under various exposure conditions.

An experimental study on the behavior of room temperature-cured reinforced geopolymer concrete flexural members involved three conventional concrete mixes and six geopolymer concrete mixes with target strengths ranging from 17 to 63 MPa. Various percentages of tension reinforcement (1.82% to 3.33%) were utilized, and all specimens underwent two-point static loading. The findings indicated that the load-carrying capacity of geopolymer concrete beams was slightly higher than that of OPC beams. Deflections at different loading stages were greater for geopolymer concrete beams. The authors recommended further extensive investigations to determine the shape and parameters of the stress block and maximum compressive strain in concrete for more accurate predictions. The specimen size used was 100 mm × 150 mm × 1500 mm.

In an experimental investigation on the flexural behavior of reinforced geopolymer concrete beams, 12 beams sized 175 mm × 250 mm × 1500 mm were tested under four-point bending with an effective span of 1200 mm. The tensile reinforcement and compressive strength of concrete were varied, and measurements for first crack load, service load, and ultimate load were obtained. The behavior of geopolymer concrete beams was found to be similar to that of OPC beams. Closer stirrup spacing than the theoretical value was provided for safety against shear. Results showed that the first crack load, service load, and ultimate load increased with higher compressive strength of concrete and a greater percentage of tensile reinforcement for geopolymer concrete.

An experimental study on the structural behavior of reinforced geopolymer concrete beams measuring 100 mm × 150 mm × 1200 mm under two-point loading was performed. Their conclusion highlighted that the flexural capacity of the beam increased with a higher longitudinal tensile reinforcement ratio. The tested ultimate moment capacity of the beams was found to be 1.35 times greater than the theoretical ultimate moment capacity. Similar to reinforced OPC concrete beams, the stiffness of the geopolymer concrete beams increased with an increase in the percentage of tensile reinforcement.

CONCLUSION

In conclusion, this review paper has provided a comprehensive overview of geopolymer concrete technology, emphasizing its performance and incorporation in RCC beams. By examining recent research findings, we have highlighted the significant strides made in enhancing the strength, durability, and sustainability of geopolymer concrete. The critical analysis of its performance against environmental factors underscores the importance of continued research and innovation in this field. Moreover, the exploration of innovative strategies, such as the incorporation of supplementary cementitious materials and nanomaterials, offers promising avenues for further improving the resilience of geopolymer concrete. The diverse range of sustainable applications discussed in this paper demonstrates the versatility and potential of geopolymer concrete in various construction projects. Overall, this review contributes valuable insights to the ongoing discourse on sustainable construction materials, advocating for the widespread adoption of geopolymer concrete for a more environmentally friendly and resilient built environment.

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